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(54) **Method of controlling power on forward link in a cellular CDMA system**

(57) A method of controlling transmission power of a plurality of base stations associated with a mobile unit in a CDMA (code division multiple access) cellular system, is disclosed. The mobile unit communicates with one base station among the plurality of base stations. According to the present invention, power of each of pilot signals respectively transmitted from the plurality of base stations is measured at the mobile unit Following this, information about a measured power value of each of the pilot signals is transmitted to the one base station. Thereafter, a first power control coefficient is determined at the one base station. The coefficient is a ratio of total pilot power values of the plurality of base stations, other than the main base station, to a pilot power value of the one base station. Subsequently, the transmission power of each of the plurality of base stations using the first power control coefficient is controlled.

FIG. 4A

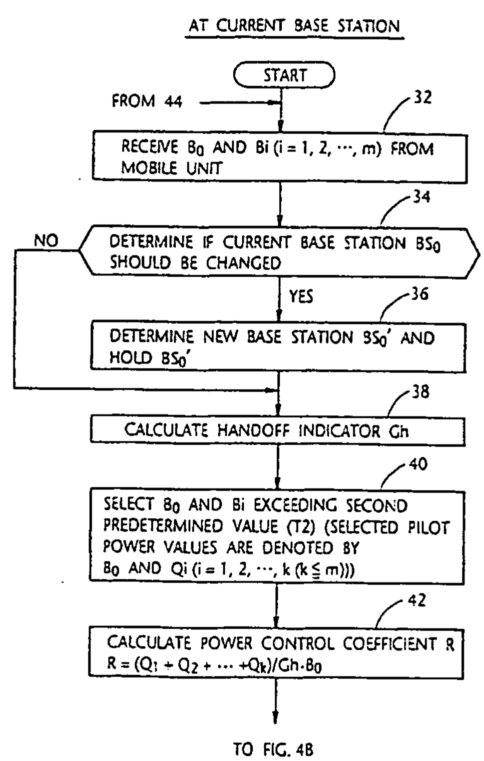

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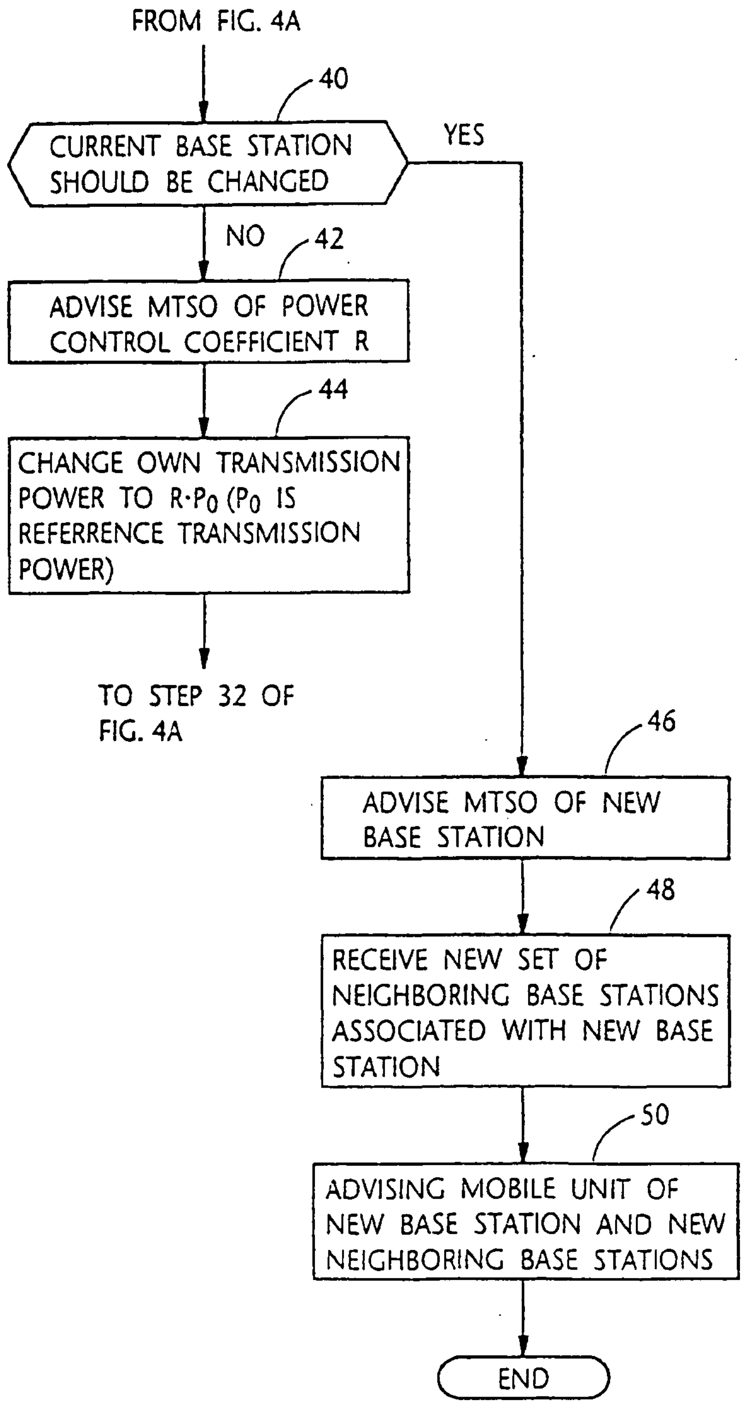
FIG. 4B


FROM FIG. 4A
40
CURRENT BASE STATION SHOULD BE CHANGED
YES
NO
42
ADVISE MTSO OF POWER CONTROL COEFFICIENT R
44
CHANGE OWN TRANSMISSION POWER TO R·P0 (P0 IS REFERRENCE TRANSMISSION POWER)
TO STEP 32 OF FIG. 4A
46
ADVISE MTSO OF NEW BASE STATION
48
RECEIVE NEW SET OF NEIGHBORING BASE STATIONS ASSOCIATED WITH NEW BASE STATION
50
ADVISING MOBILE UNIT OF NEW BASE STATION AND NEW NEIGHBORING BASE STATIONS
END

Description

The present invention relates generally to techniques in transmission power control of base stations in a CDMA (code division multiple access) cellular system using spread spectrum techniques. More specifically, the present invention relates to a power control method on forward links (viz., base station to mobile unit links) in a CDMA cellar system in order to increase capacity of the overall system.

As is well known in the art, in a CDMA system, all users transmits simultaneously and at the same frequency. The transmitted signals occupy the entire system bandwidth, and code sequences, which are orthogonal, are used to separate one user from another. That is, each user is assigned a unique code sequence. The use of the same frequency in the overall system indicates that no "handoff" from one frequency to another is needed as in FDMA (frequency division multiple access) and TDMA (time division multiple access) systems. This is called a soft handoff that is disclosed in United States Patent No. 5,101,501 by way of example.

In a CDMA system, there is no distinct limit on the number of users. The system performance for all users degrades gradually as the number of active users increases. More specifically, mobile units in the CDMA system transmit independently (viz., asynchronously) from each other. This means that their signals arrive randomly at the base station and therefore, the crosscorrelation between these randomly, arrived signals is not zero and thus causes interference.

The major difficulty with CDMA is a so-called "near-far effect", which occurs when a weak signal received at the base station from a distant mobile unit is overpowered by a strong signal from a nearby interferer. To reduce the near-far effect, power control on reverse links (viz., mobile unit to base station links) is necessary.

Additionally, the system capacity is expanded by power control on the forward links (viz., base station to mobile unit links). One example of such power control on the forward link is disclosed in Japanese Laid-open Patent Application No. 7-38496. According to this conventional technique, each of the mobile units in a given cell receives a pilot signal from the own base station, measures a signal-to-noise (S/N) ratio using the pilot signal received, and then informs the base station of the measurement results. The base station responds to the measurement results and controls the transmission power on the forward link of each mobile unit. Thus, the S/N ratios at the mobile units within the base station are improved and approach to a predetermined level (viz., roughly equalized). As a result, a low level of interference is achieved at each mobile unit.

This conventional technique, however, has suffered from a drawback. That is, when a SIN ratio at a given mobile unit is lowered due to increase in the number of the active users in the cell, the base station is responsive to the reduced S/N ratio and raises the power on the forward link to the given mobile unit This in turn undesirably lowers the S/N ratio at each of other mobile units, with the result that the S/N ratio of the first base station again is lowered. This cycle is repeated and eventually the power of each forward link of many mobile units undesirably is raised to the maximum value.

Further, it takes a relatively long time until the lowering of interference is carried out after the measurement of the S/N ratio. Therefore, during the long feedback time, the S/N ratio measured has undesirably changed. In such a case, a precise control is no longer expected.

It is therefore an object of the present to provide a method of achieving a low level of interference especially in the vicinity of a cell boundary even if the number of active users increases, whereby it is possible to keep constant the system performance for all users.

One aspect of the present invention resides in a method of controlling transmission power of a plurality of base stations associated with a mobile unit in a CDMA (code division multiple access) cellular system, the mobile unit communicating with one base station among the plurality of base stations, the method comprising the steps of: (a) measuring, at the mobile unit, power of each of pilot signals respectively transmitted from the plurality of base stations; (b) advising the one base station of information about a measured power value of each of the pilot signals; (c) determining, at the one base station, a first power control coefficient which is a ratio of total pilot power values of the plurality of base stations, other than the main base station, to a pilot power value of the one base station; and (d) controlling the transmission power of each of the plurality of base stations using the first power control coefficient.

The features and advantages of the present invention will become more clearly appreciated from the following description taken in conjunction with the accompanying drawings in which like elements are denoted by like reference numerals and in which:

Fig. 1 is a sketch schematically showing a plurality of cells, base stations, etc. provided in a CDMA cellular system;

Fig. 2 is a time slot format of one frame for acquiring pilot signal power on forward links of base stations;

Figs. 3, 4A and 4B are each flow chart which shows steps which characterize a first embodiment of the present invention;

Figs. 5A and 5B are each flow chart which shows steps which characterize a second embodiment of the present invention;

Fig. 6 is a flow chart which shows steps which characterize a third embodiment of the present invention;

Figs. 7A, 7B and 8 are each flow chart which shows steps which characterize a fourth embodiment of the present invention; and

Figs. 9A and 9B are each flow chart which shows

steps which characterize a fifth embodiment of the present invention.

Referring to Fig. 1, there are shown only three cells 10, 12, and 14 which respectively include base stations BS1, BS2, and BS3. Further, as shown, another three base stations BS4-BS6 are respectively assigned to other three cells (not shown). As is well known in the art, all the base stations in the system, including BS1-BS6, are coupled to a MTSO (mobile telephone switching office) 16, which supervises an overall operation of the system and which is in turn coupled to a public switched telephone network. Still further, two mobile units 18 and 20 are shown in Fig. 1. The mobile unit 18 is located in the vicinity of the boundary between the cells 10 and 12 and simultaneously communicates with two base stations BS1 and BS2 in order to attain the above mentioned soft handoff. However, it is to be noted that the mobile unit 18 in fact establishes a speech channel with either BS1 or BS2. It is assumed that the other mobile unit 20 is not located in the vicinity of a cell boundary and thus keeps communication only with the base station BS1.

The present invention is not directly concerned with a handoff operation but directed to effectively achieve a low level of interference in the vicinity of a cell boundary. Therefore, the system capacity can markedly be increased (viz., the number of active users can be increased without inducing degradation of signal quality).

Each of the base stations in the system constantly transmits a pilot signal the transmission power of which may vary depending on the cell size. However, in the instant disclosure, it is assumed that each base station radiates the corresponding pilot signal with a predetermined (constant) power for the sake of simplifying the description. Each pilot signal is assigned a unique code and thus, it is possible for the mobile unit to discriminate which base station generates the pilot signal.

On the other hand, each mobile unit is provided with a device for measuring strength of each of the pilot signals arriving at the mobile unit. More specifically, the mobile unit selectively acquires a predetermined number of pilot signals using codes which are applied thereto from a currently communicating base station.

Fig. 2 is a diagram showing a pilot signal acquiring (or measuring) frame which consists of six time slots 1-6 in this instance. Each mobile unit acquires one pilot signal during one time slot and thus, is able to cyclically receive a total of six different pilot signals on a frame-by-frame basis in this particular case. The mobile unit typically measures the power (viz., signal strength) of one pilot signal during one time slot. If more than six pilot signals should be received at the mobile unit, the frame length can be expanded to meet the requirement. The instantaneous power of the pilot signal typically varies drastically and thus, it is a current practice to average the power over a sufficiently long time. Throughout the instant disclosure, the power of a pilot signal means an average value.

It is assumed that a mobile unit has already established a speech channel with a given base station (sometimes referred to as a current base station). In this case, the mobile unit receives, from the current base station, information indicating a set of neighboring base stations. Based on this information, the mobile unit measures the power of each of the pilot signals transmitted from the neighboring base stations in addition to the power of the pilot signal from the current base station.

A first embodiment of the present invention will be described with reference to Figs. 3, 4A and 4B.

In Fig. 3, at step 22, the mobile unit checks to determine if the current base station should is changed (viz., handoff). The instruction of changing the current base station (denoted by BS_0) is advised from the current base station itself. If the current should be changed, the routine goes to step 24 whereat a new base station is advised together with a new set of neighboring base stations BS1 (i=1, 2, ..., n)(n is five in the case shown in Fig. 1 for example). On the other hand, if the answer is negative at step 22, the routine proceeds to step 26. At this step 26, the power of each of the pilot signals on the forward link (viz., inbound link or base station to mobile unit link) in connection with the base station BS_0 and BSi are measured. Following this, at step 28, each of the measured pilot signal's power values is compared with a predetermined value (T1) so as to select the values exceeding T1. The power values thus selected are denoted by B_0 and Bi (i=1, 2, ..., m (m≦n)) wherein B_0 is the power value of BS_0 and Bi are power values of BSi. Thereafter, at step 30, the power values B_0 and Bi are transmitted to the current base station BS_0.

Figs. 4A and 4B shows steps which are implemented at the current base station. At step 32, the base station receives the power values B_0 and Bi from the mobile unit. Thereafter, at steps 34 and 36, a check is made to determine if the current base station should be changed based on the power values B_0 and Bi received at step 32. If the change of the base station is to be implemented, the data indicating the new base station (denoted by BS'_0) is stored in the current base station. If the change of the current base station is not required, the routine directly goes to step 38 at which a handoff indicator Gh is calculated as follows. In this case, Bi are rewritten by Qi

$$Gh = (Q_1 + Q_2 + \dots + Q_m)/B_0 \qquad (1)$$

Following this, at step 40, the power values B_0 and Qi, exceeding a second predetermined value (T2), are selected. The selected power values are denoted by B_0 and Qi (i=1, 2,..., k (k ≦ m). It is to be noted that the value B_0 is selected in that this value is the largest one. Following this, a power control coefficient R is calculated

as follows at step .

$$R = (Q_1+Q_2+...+Q_K)/Gh \cdot B_0 \quad (2)$$

Therefore, since BR can be rewritten using equation (1) as follows.

$$R= (Q_1+Q_2+...+Q_K()/Q_1 + Q_2+ ... +Q_m) \quad (3)$$

Thereafter, the routine goes to the steps of Fig. 4B wherein if the current base station should not changed the routine go through steps 42 and 44 to step 32 (Fig. 4A). On the other hand, if the current station should be changed, the routine goes through steps 46, 48 and 50 and is terminated.

A second embodiment of the present invention will be described with reference to Figs. 5A and 5B.

As shown in Fig. 5A, steps 32' to 40' are identical to step 32 to 40 and hence further descriptions thereof are omitted for brevity. The second embodiment features that the power control coefficient R is derived using total transmission power values (Pi) of the base stations and the corresponding mentioned power values Qi. In Fig. 5A, Pmas indicates the maximum allowable power value of each base station. On the other hand, the power control coefficient R should be in a range between previously determined minimum and maximum values (Rmin and Rmax). The manner of defining the coefficient R between Rmin and Rmax is shown in Fig. 5B. After implementing either step 62 or step 58, the routine goes to the program which is exactly identical to that shown in Fig. 4B.

A third embodiment of the present invention will be described with reference to Figs. 6.

As shown in Fig. 6, steps 32' to 40' are identical to step 32 to 40 and hence further descriptions thereof are omitted for brevity. The third embodiment features that the number of pilot signals (m in this case) is checked whether or not the number exceeds the previously determined maxim number of pilot signals (Nmax). If m>Nmax, steps 72 and 74 are implemented and the routine proceeds to step 76. Otherwise, the routine implements steps 78 and 80 and then goes to step 76. After carrying out step 76, the routine goes to the program which is exactly identical to that shown in Fig. 4B.

A fourth embodiment of the present invention will be described with reference to Figs. 7A, 7B and 8. This embodiment is to carry out, at the mobile unit, steps which are executed in the current base station in the first embodiment. Therefore, the burden on the base station can be reduced.

As shown in Fig. 7A, steps 22' to 26' are identical to step 32 to 40, while as shown in Fig. 7B, steps 34' to 42' are identical to steps 34 to 42 shown in Fig. 4A. At step 90 (Fig. 7B), if the current base station should be changed, data indicating the new base station is informed to the current base station together with the power control coefficient R. Otherwise, only the coefficient R is transmitted to the current base station BS_0. After step 90, the routine returns to step 22' of Fig. 7A in order to repeat the operations. On the other hand, as shown in Fig. 8, at step 92, the current base station receives the information which the mobile unit transmitted at step 90. Following this, steps 40' to 50' are implemented which are respectively identical to steps 40 to 50 of Fig. 4B.

A fifth embodiment of the present invention will be described with reference to Figs. 9A and 9B. The instant embodiment features that the calculated power control coefficient (denoted by R' in step 42') is checked to determined if R' is within a predetermined range if the current base station should not be changed. For this purpose, the power control coefficient R is initialized at step 100 (viz., R is set to one (1)). The following steps 22' to 40' are exactly identical to steps 22 to 40 shown in Figs. 7A and 7B. At step 102, a check is made to determine if the current base station should be changed. If the answer is negative at this step, the routine goes to step 104 at which the calculated power control coefficient R' is checked if R' is within the predetermined range as mentioned above. If the answer at step 104 is NO, the calculated coefficient R' is adopted and then advised to the base station BS_0 at steps 106 and 108.

It will be understood that the above disclosure is representative of five possible embodiments of the present invention and that the concept on which the invention is based is not specifically limited thereto.

Claims

1. A method of controlling transmission power of a plurality of base stations associated with a mobile unit in a CDMA (code division multiple access) cellular system, said mobile unit communicating with one base station among said plurality of base stations, said method comprising the steps of:

    (a) measuring, at said mobile unit, power of each of pilot signals respectively transmitted from said plurality of base stations;
    (b) advising said one base station of information about a measured power value of each of the pilot signals;
    (c) determining, at said one base station, a first power control coefficient which is a ratio of total pilot power values of said plurality of base stations, other than said main base station, to a pilot power value of said one base station; and
    (d) controlling the transmission power of each of said plurality of base stations using said first power control coefficient.

2. A method as claimed in claim 1, wherein the power of each of the pilot signals is compared, at said mobile unit, with a first predetermined value after step (a), the power exceeding the first predetermined threshold being selected, and information about the values of selected power being sent to said main base station.

3. A method as claimed in claim 1 or 2, wherein the power value of each of the pilot signals is compared with a second predetermined value after step (b), and the power values each exceeding the second predetermined threshold being selected and used to determine said first power coefficient.

4. A method as claimed in claim 1, 2, or 3 further comprising the steps of:

receiving, at said one base station, total transmission power of each of said plurality of base stations from a MTSO (mobile telephone switching office) which is provided in said CDMA cellular system to supervise overall operations of the system;
determining, at said one base station, a second power control coefficient which is a ratio of $(P_1Q_1+P_2Q_2+...+P_kQ_k)$ to $(Gh \cdot Pm \cdot Q_0)$ where $P_i(i=1, 2, ... k)$ is the total transmission power of an i-th base station, Q_i $(i= 1,2,...k)$ is the power value of the pilot signal of an i-th base station other than said one base station, Pm is a maximum transmission power of each of the base stations, and Q_0 is the power value of pilot signal of said one base station;
controlling the transmission power of each of said plurality of base stations using said second power control coefficient instead of said first power control coefficient.

FIG. 1

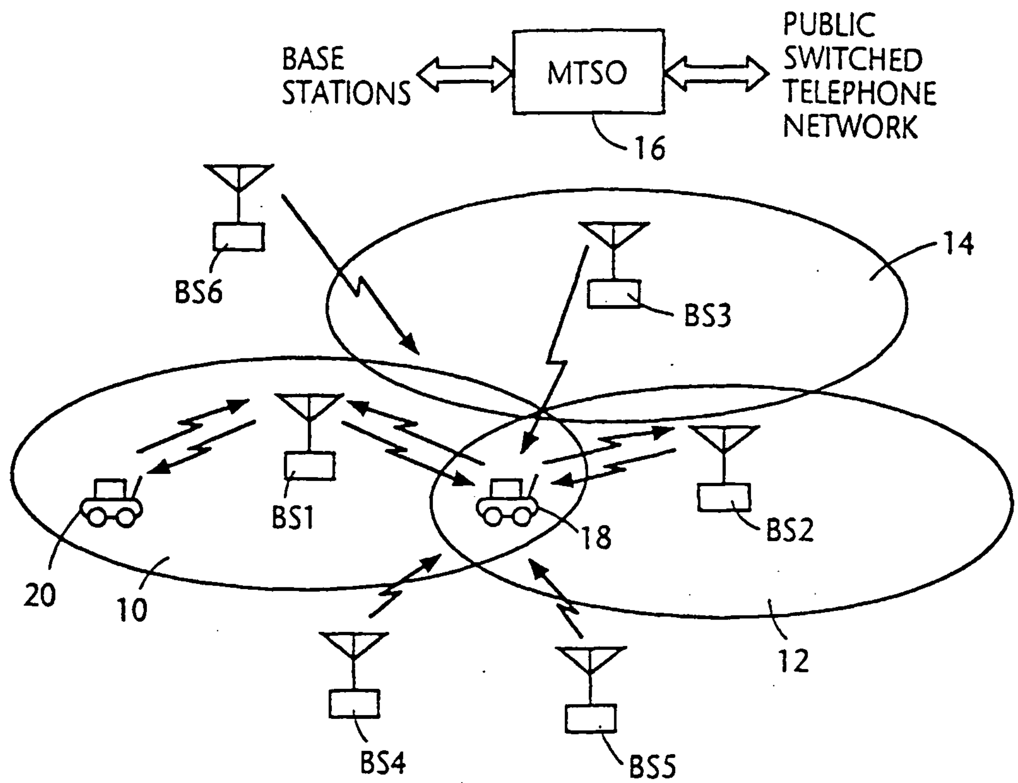

BASE
STATIONS
MTSO
PUBLIC
SWITCHED
TELEPHONE
NETWORK
16
14
BS6
BS3
BS1
18
BS2
20
10
12
BS4
BS5

FIG. 2

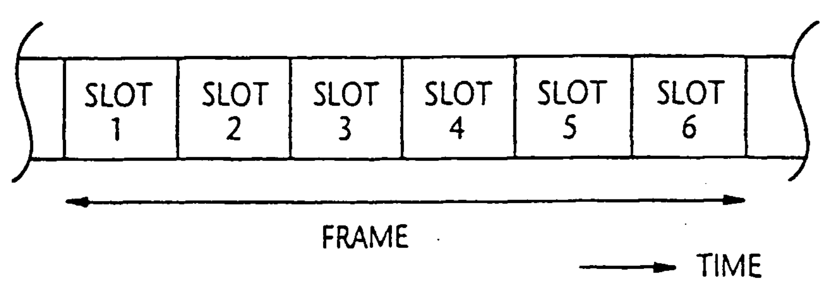

SLOT 1
SLOT 2
SLOT 3
SLOT 4
SLOT 5
SLOT 6
FRAME
TIME

FIG. 3

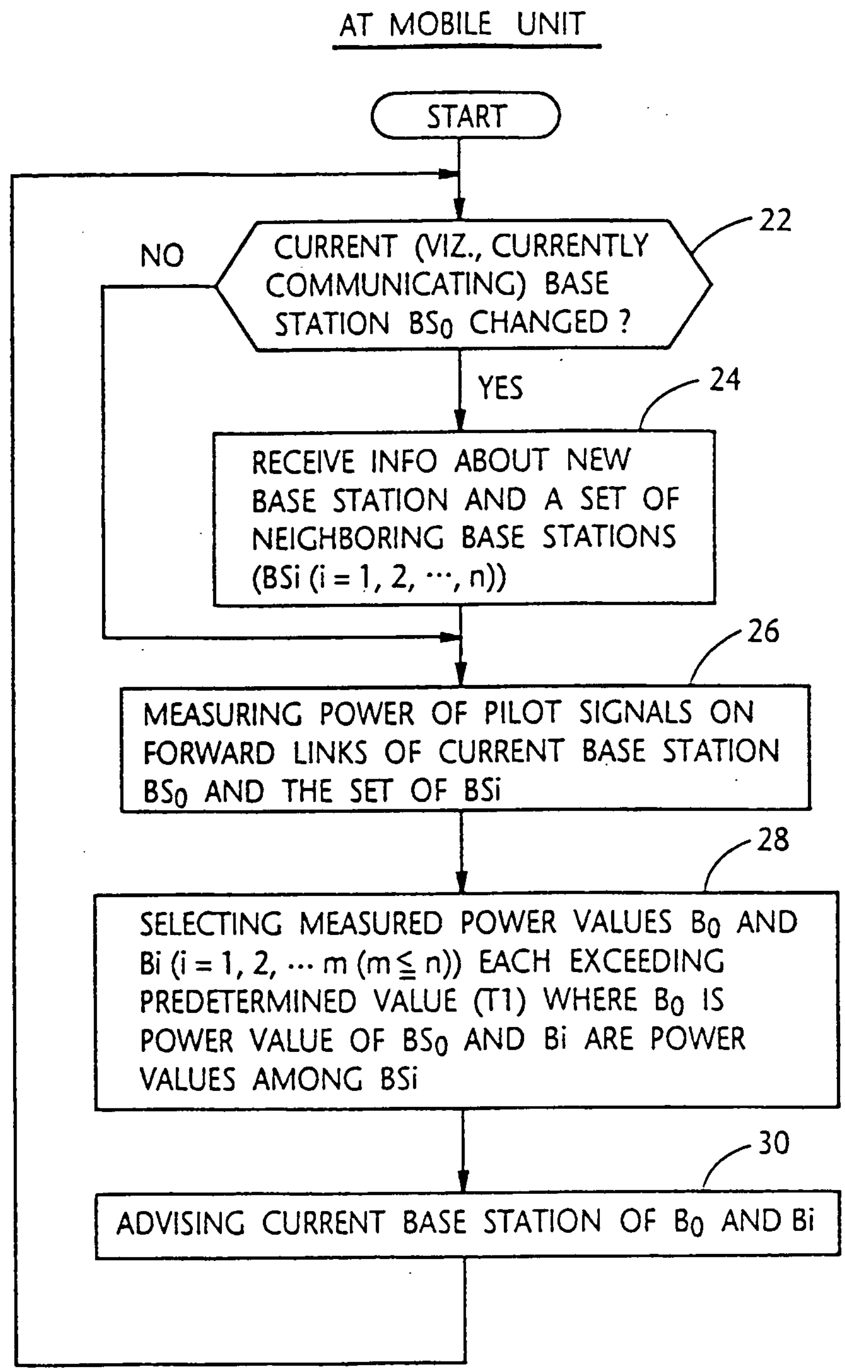

AT MOBILE UNIT
START
CURRENT (VIZ., CURRENTLY COMMUNICATING) BASE STATION BS0 CHANGED ?
22
NO
YES
24
RECEIVE INFO ABOUT NEW BASE STATION AND A SET OF NEIGHBORING BASE STATIONS (BSi (i = 1, 2, ···, n))
26
MEASURING POWER OF PILOT SIGNALS ON FORWARD LINKS OF CURRENT BASE STATION BS0 AND THE SET OF BSi
28
SELECTING MEASURED POWER VALUES B0 AND Bi (i = 1, 2, ··· m (m ≦ n)) EACH EXCEEDING PREDETERMINED VALUE (T1) WHERE B0 IS POWER VALUE OF BS0 AND Bi ARE POWER VALUES AMONG BSi
30
ADVISING CURRENT BASE STATION OF B0 AND Bi

FIG. 4A

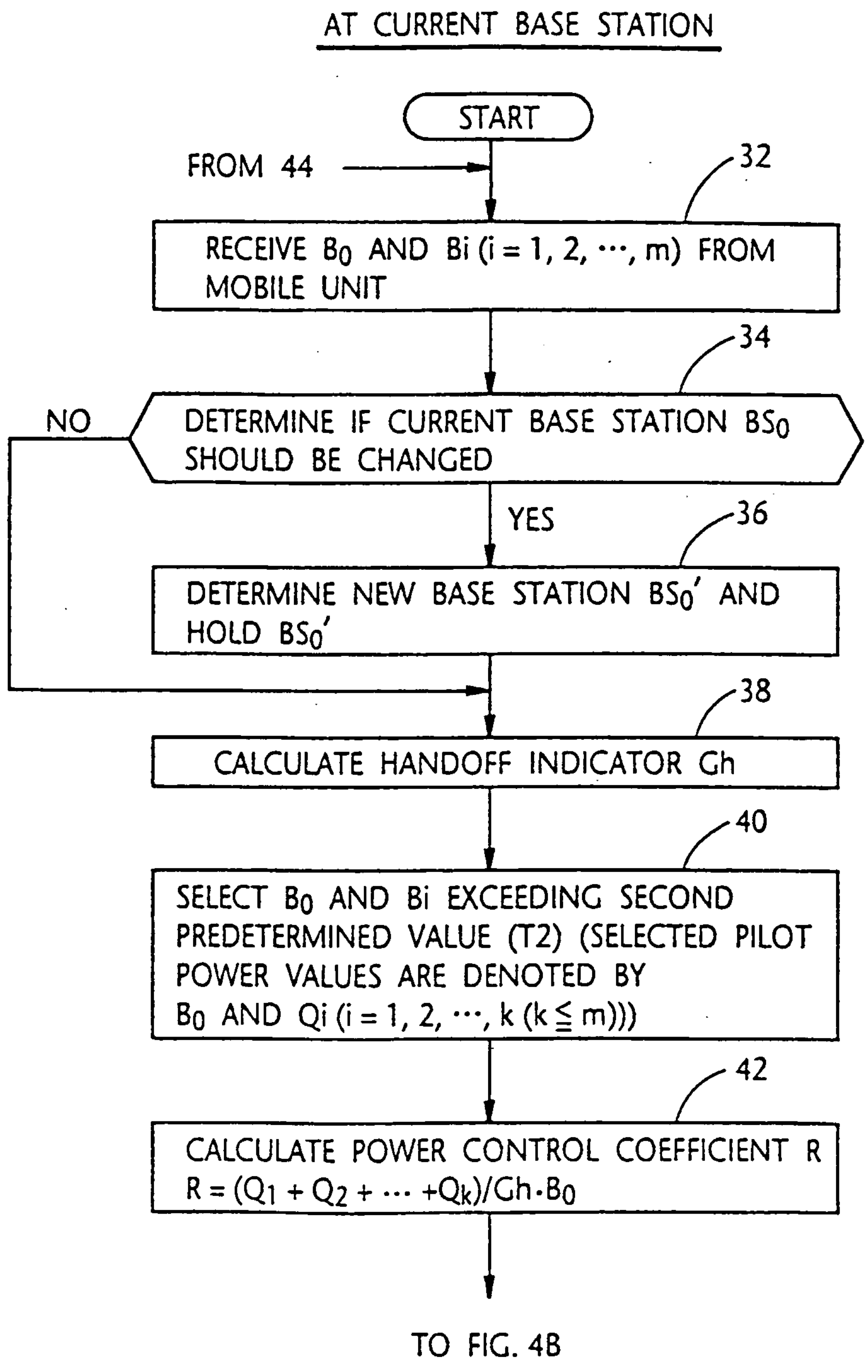

AT CURRENT BASE STATION
START
FROM 44
32
RECEIVE B_0 AND Bi (i = 1, 2, ⋯, m) FROM MOBILE UNIT
34
NO
DETERMINE IF CURRENT BASE STATION BS_0 SHOULD BE CHANGED
YES
36
DETERMINE NEW BASE STATION BS_0' AND HOLD BS_0'
38
CALCULATE HANDOFF INDICATOR Gh
40
SELECT B_0 AND Bi EXCEEDING SECOND PREDETERMINED VALUE (T2) (SELECTED PILOT POWER VALUES ARE DENOTED BY B_0 AND Qi (i = 1, 2, ⋯, k ($k \leqq m$)))
42
CALCULATE POWER CONTROL COEFFICIENT R
$R = (Q_1 + Q_2 + \cdots + Q_k)/Gh \cdot B_0$
TO FIG. 4B

FIG. 4B

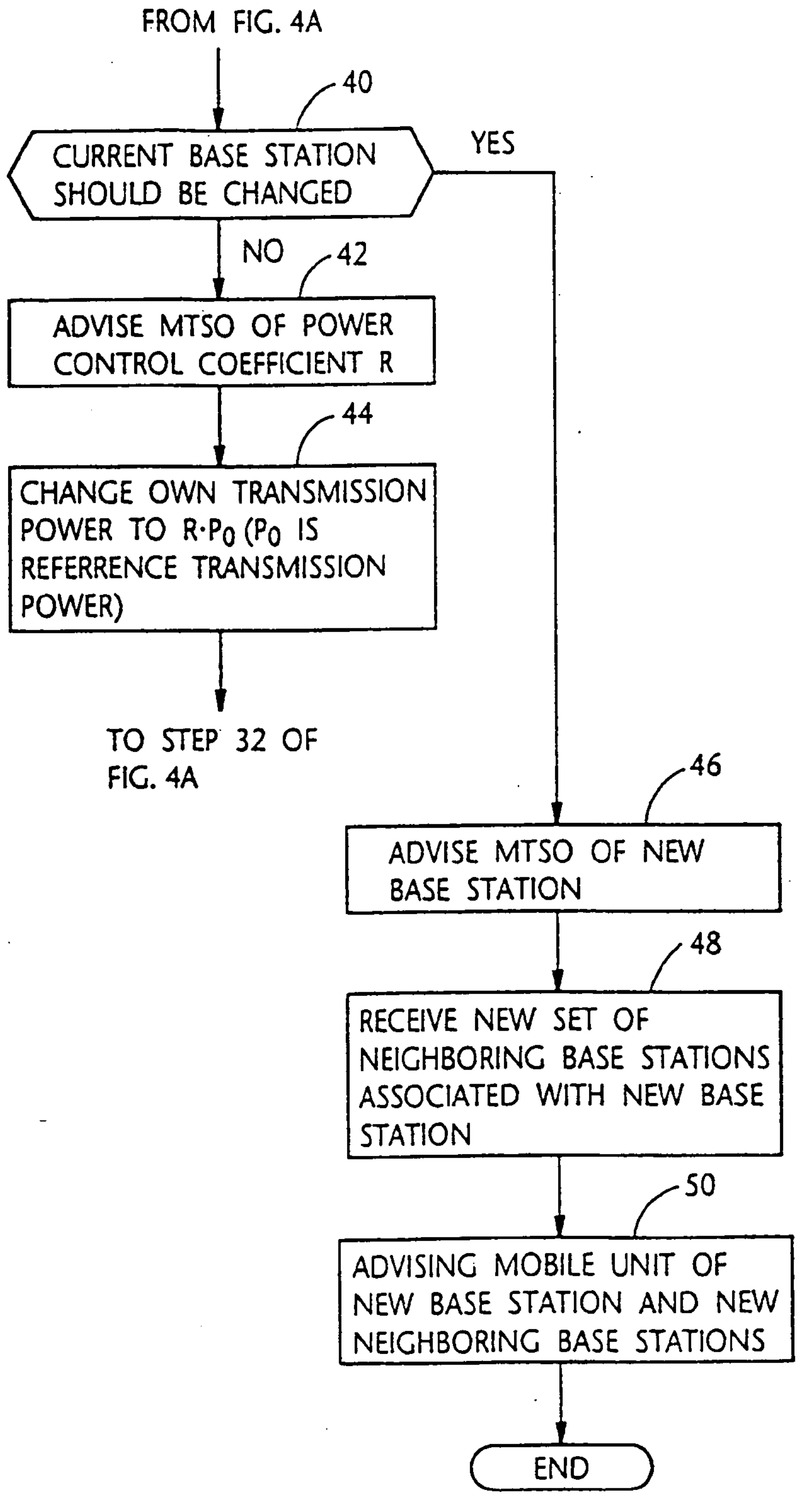

FROM FIG. 4A
40
CURRENT BASE STATION SHOULD BE CHANGED
YES
NO
42
ADVISE MTSO OF POWER CONTROL COEFFICIENT R
44
CHANGE OWN TRANSMISSION POWER TO R·P0 (P0 IS REFERRENCE TRANSMISSION POWER)
TO STEP 32 OF FIG. 4A
46
ADVISE MTSO OF NEW BASE STATION
48
RECEIVE NEW SET OF NEIGHBORING BASE STATIONS ASSOCIATED WITH NEW BASE STATION
50
ADVISING MOBILE UNIT OF NEW BASE STATION AND NEW NEIGHBORING BASE STATIONS
END

FIG. 5A AT CURRENT BASE STATION

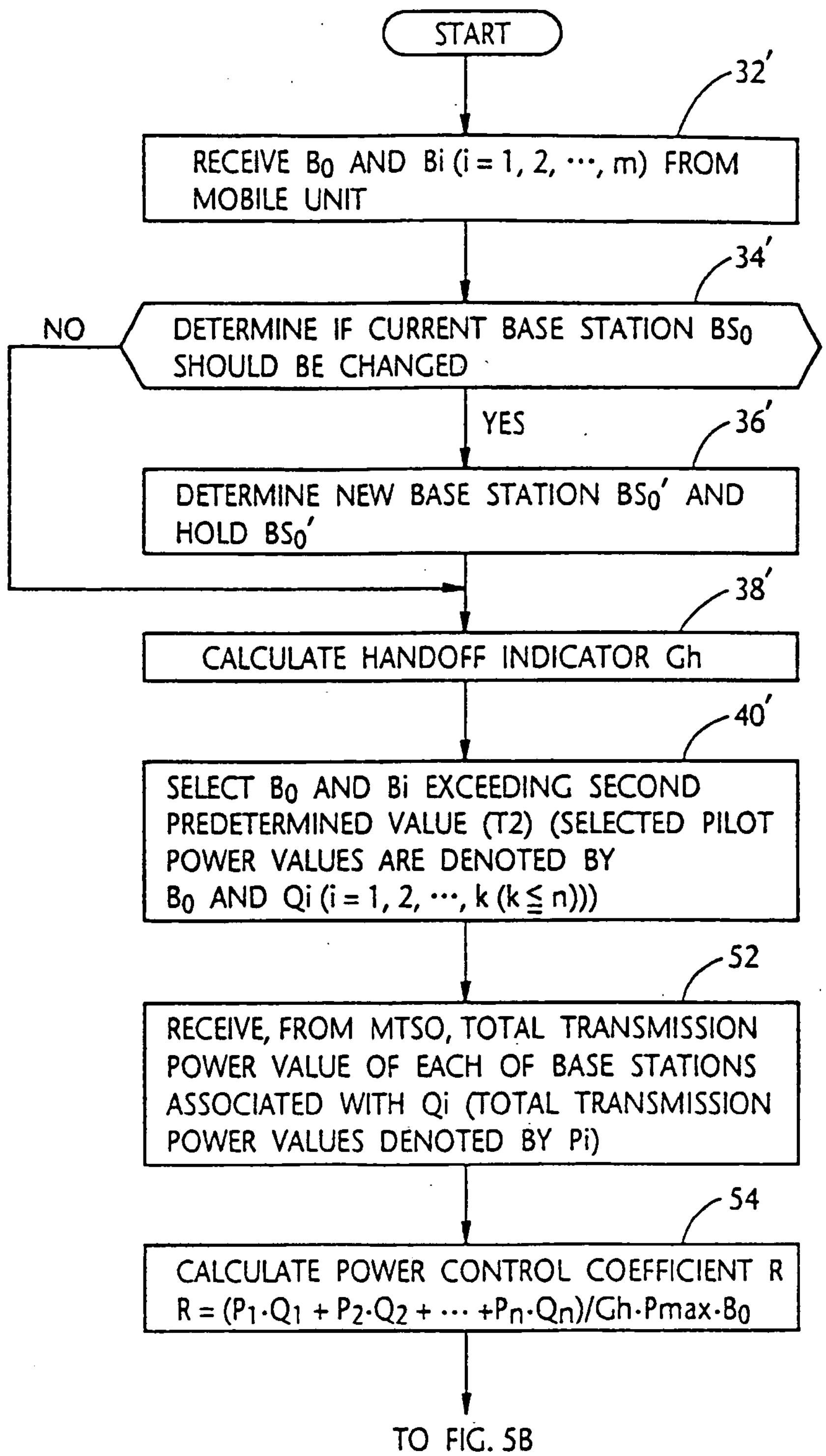


FIG. 5B

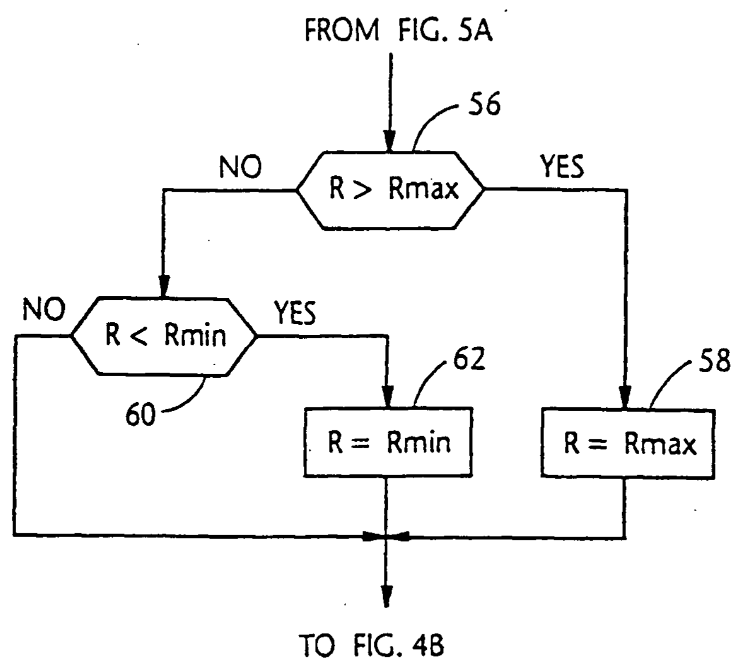

FROM FIG. 5A
56
NO
R > Rmax
YES
NO
R < Rmin
YES
62
58
60
R = Rmin
R = Rmax
TO FIG. 4B

FIG. 6

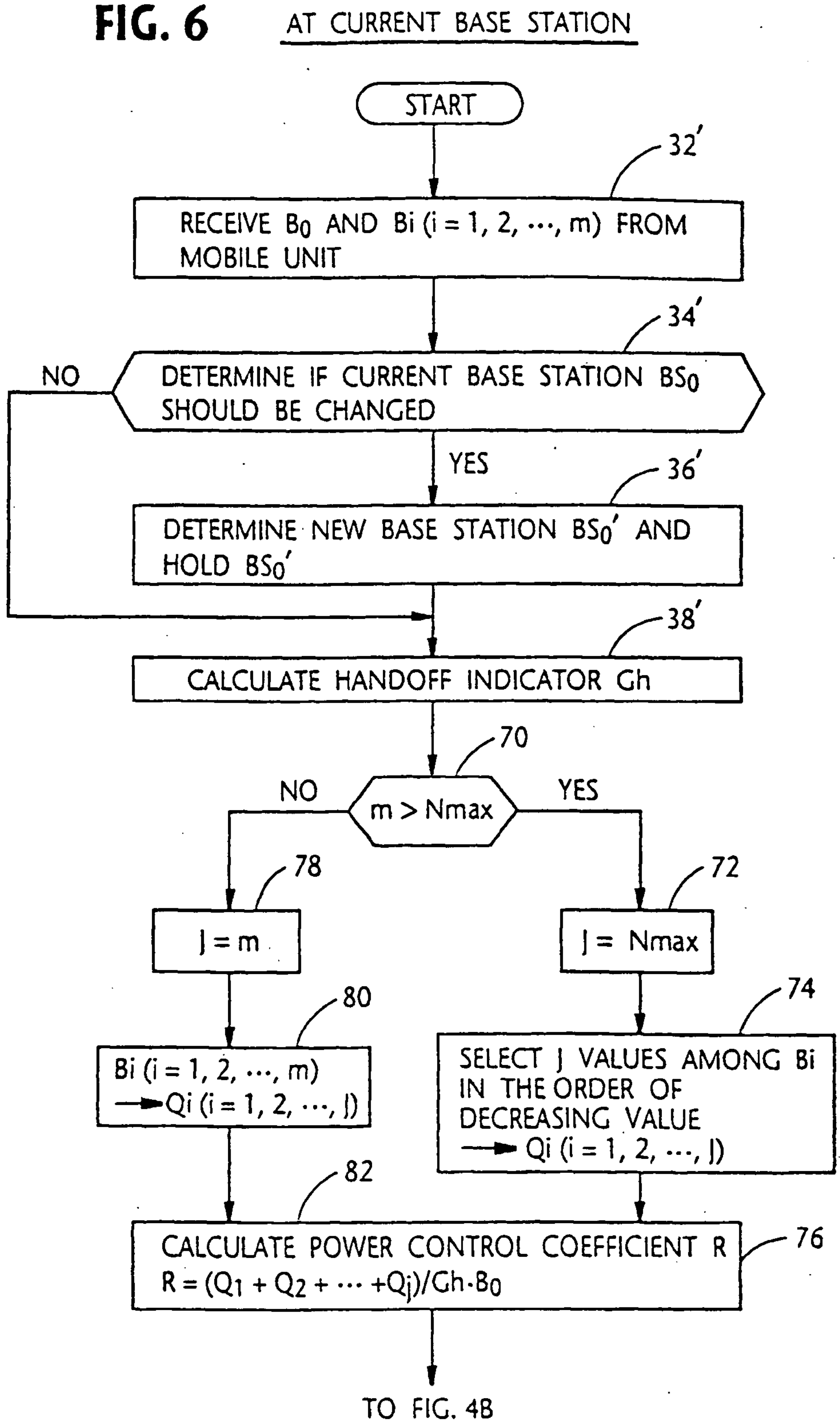

AT CURRENT BASE STATION
START
32'
RECEIVE B0 AND Bi (i = 1, 2, ···, m) FROM MOBILE UNIT
34'
NO
DETERMINE IF CURRENT BASE STATION BS0 SHOULD BE CHANGED
YES
36'
DETERMINE NEW BASE STATION BS0' AND HOLD BS0'
38'
CALCULATE HANDOFF INDICATOR Gh
70
NO
m > Nmax
YES
78
J = m
72
J = Nmax
80
Bi (i = 1, 2, ···, m) → Qi (i = 1, 2, ···, J)
74
SELECT J VALUES AMONG Bi IN THE ORDER OF DECREASING VALUE → Qi (i = 1, 2, ···, J)
82
CALCULATE POWER CONTROL COEFFICIENT R
R = (Q1 + Q2 + ··· +Qj)/Gh·B0
76
TO FIG. 4B

FIG. 7A

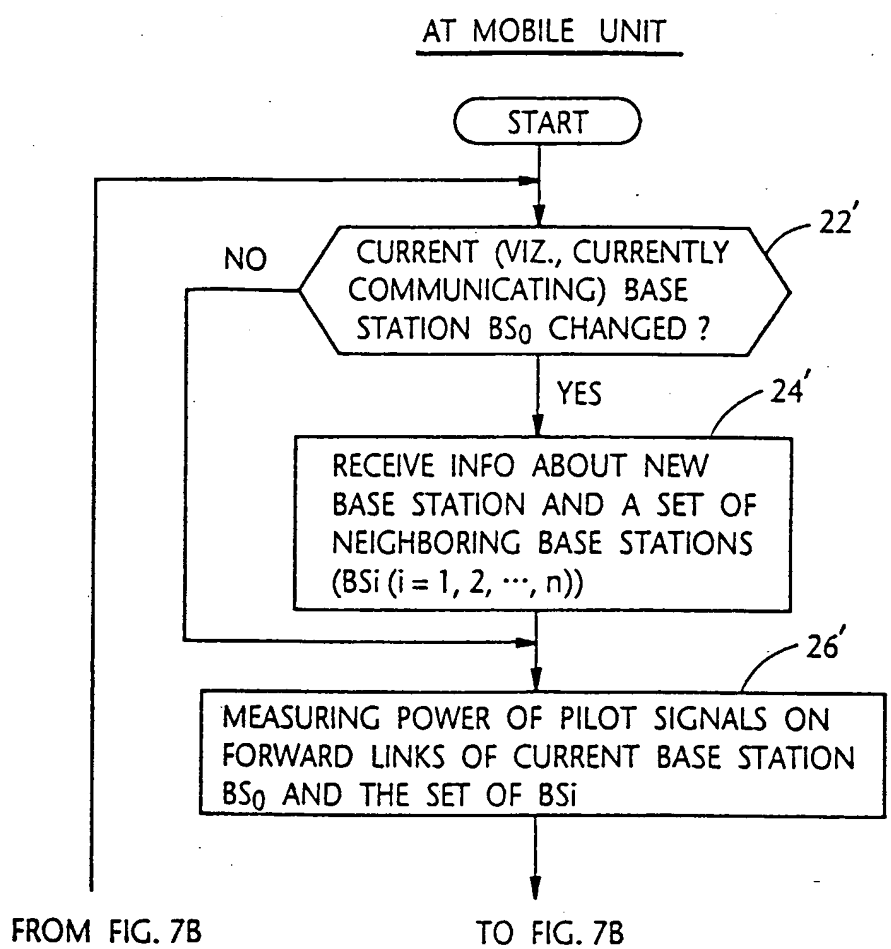

AT MOBILE UNIT
START
NO
CURRENT (VIZ., CURRENTLY COMMUNICATING) BASE STATION BS0 CHANGED ?
22'
YES
24'
RECEIVE INFO ABOUT NEW BASE STATION AND A SET OF NEIGHBORING BASE STATIONS (BSi (i = 1, 2, ···, n))
26'
MEASURING POWER OF PILOT SIGNALS ON FORWARD LINKS OF CURRENT BASE STATION BS0 AND THE SET OF BSi
FROM FIG. 7B
TO FIG. 7B

FIG. 7B

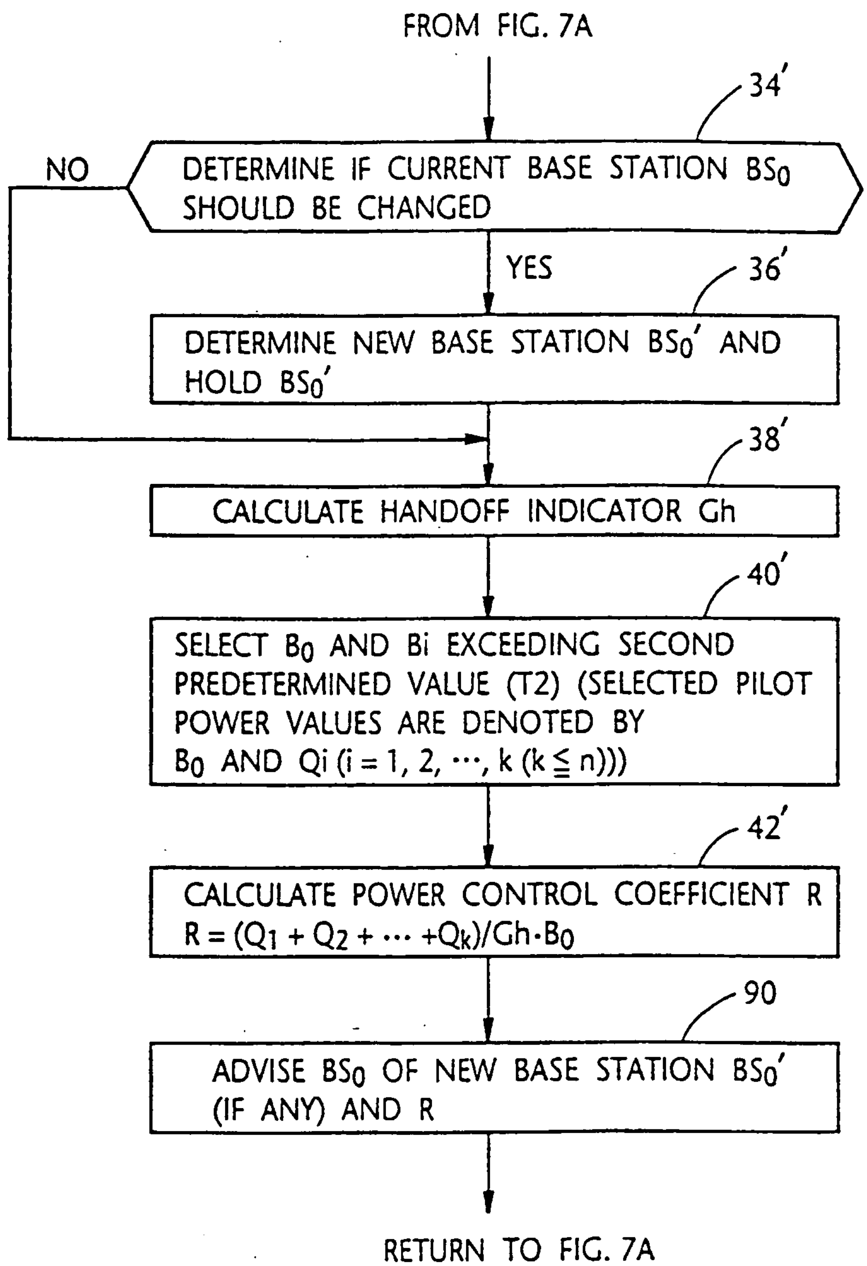

FROM FIG. 7A
34'
NO
DETERMINE IF CURRENT BASE STATION BS_0 SHOULD BE CHANGED
YES
36'
DETERMINE NEW BASE STATION BS_0' AND HOLD BS_0'
38'
CALCULATE HANDOFF INDICATOR Gh
40'
SELECT B_0 AND Bi EXCEEDING SECOND PREDETERMINED VALUE (T2) (SELECTED PILOT POWER VALUES ARE DENOTED BY B_0 AND Qi ($i = 1, 2, \cdots, k$ ($k \leqq n$)))
42'
CALCULATE POWER CONTROL COEFFICIENT R
$R = (Q_1 + Q_2 + \cdots + Q_k)/Gh \cdot B_0$
90
ADVISE BS_0 OF NEW BASE STATION BS_0' (IF ANY) AND R
RETURN TO FIG. 7A

FIG. 8

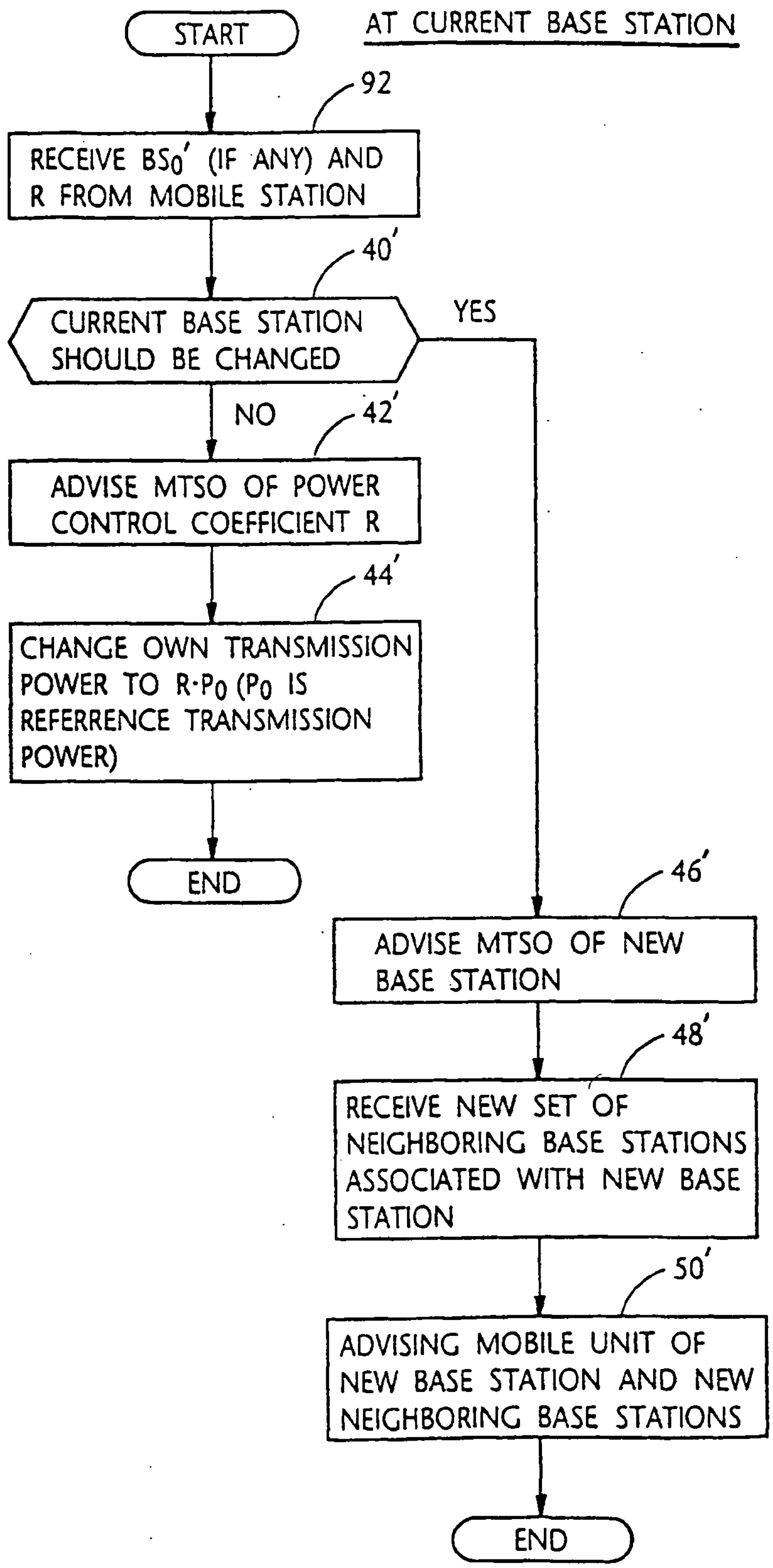

AT CURRENT BASE STATION
START
92
RECEIVE BS_0' (IF ANY) AND R FROM MOBILE STATION
40'
CURRENT BASE STATION SHOULD BE CHANGED
YES
NO
42'
ADVISE MTSO OF POWER CONTROL COEFFICIENT R
44'
CHANGE OWN TRANSMISSION POWER TO $R \cdot P_0$ (P_0 IS REFERRENCE TRANSMISSION POWER)
END
46'
ADVISE MTSO OF NEW BASE STATION
48'
RECEIVE NEW SET OF NEIGHBORING BASE STATIONS ASSOCIATED WITH NEW BASE STATION
50'
ADVISING MOBILE UNIT OF NEW BASE STATION AND NEW NEIGHBORING BASE STATIONS
END

FIG. 9A

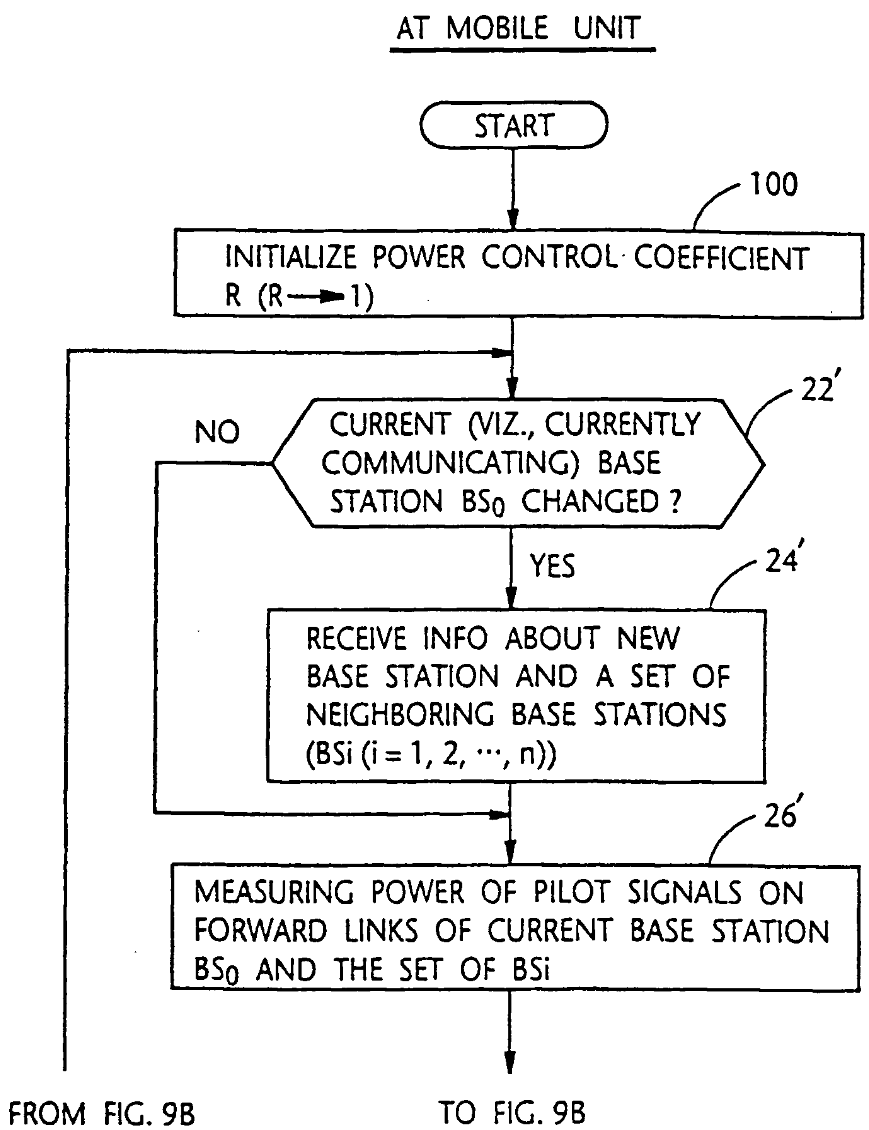
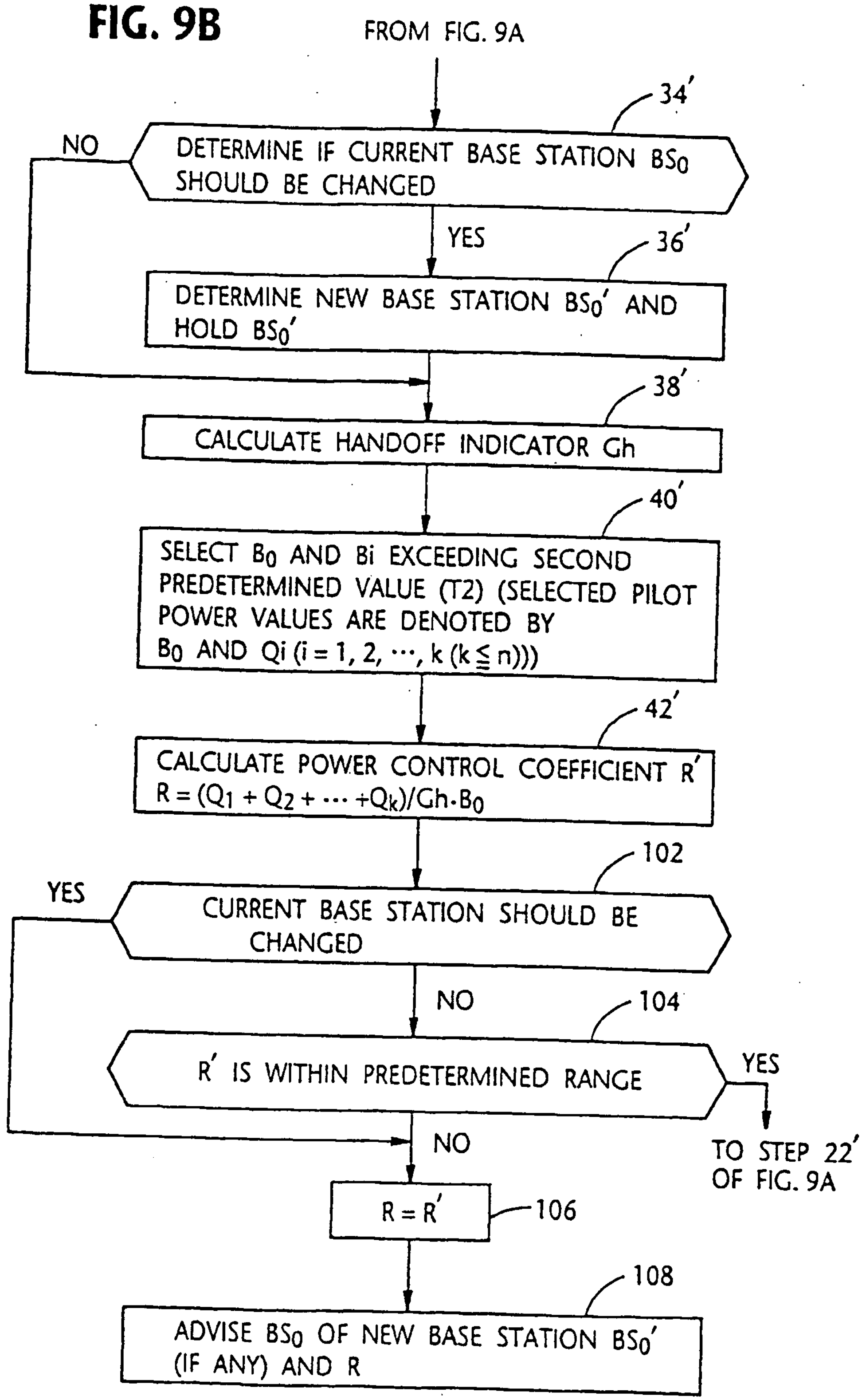

AT MOBILE UNIT
START
100
INITIALIZE POWER CONTROL COEFFICIENT R (R→1)
22′
NO
CURRENT (VIZ., CURRENTLY COMMUNICATING) BASE STATION BS_0 CHANGED ?
YES
24′
RECEIVE INFO ABOUT NEW BASE STATION AND A SET OF NEIGHBORING BASE STATIONS (BSi (i = 1, 2, ···, n))
26′
MEASURING POWER OF PILOT SIGNALS ON FORWARD LINKS OF CURRENT BASE STATION BS_0 AND THE SET OF BSi
FROM FIG. 9B
TO FIG. 9B

FIG. 9B


FROM FIG. 9A
34'
NO
DETERMINE IF CURRENT BASE STATION BS_0 SHOULD BE CHANGED
YES
36'
DETERMINE NEW BASE STATION BS_0' AND HOLD BS_0'
38'
CALCULATE HANDOFF INDICATOR Gh
40'
SELECT B_0 AND Bi EXCEEDING SECOND PREDETERMINED VALUE (T2) (SELECTED PILOT POWER VALUES ARE DENOTED BY B_0 AND Qi ($i = 1, 2, \cdots, k$ ($k \leqq n$)))
42'
CALCULATE POWER CONTROL COEFFICIENT R'
$R = (Q_1 + Q_2 + \cdots + Q_k)/Gh \cdot B_0$
102
YES
CURRENT BASE STATION SHOULD BE CHANGED
NO
104
R' IS WITHIN PREDETERMINED RANGE
YES
TO STEP 22' OF FIG. 9A
NO
R = R'
106
108
ADVISE BS_0 OF NEW BASE STATION BS_0' (IF ANY) AND R